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FLASH BURN CASUALTIES FROM NUCLEAR EXPLOSIONS: EFFECTS FOR SKIN--ETC(U)
SEP 80 J S WICKLUND
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Skin color is an important factor in flash burns from a nuclear explosion. Unless the skin is protected, second- and third-degree burns are suffered at ranges of several kilometers: for a weapon yield of 300 kT, very-dark-skinned persons are at risk a full kilometer farther from the detonation than very-light-skinned persons.

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20. Abstract (Cont'd)

If evasive action is taken so that the skin is not exposed, severe burns can still be suffered under a summer uniform. Troops wearing summer uniforms become casualties at ranges where airblast and nuclear radiation are negligible.

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1. INTRODUCTION

Skin burns produced directly by the flash of thermal radiation from the fireball are a major casualty-producing result of a nuclear explosion. It has been estimated that these flash burns caused 20 to 30 percent of the fatalities in Hiroshima and Nagasaki. About 42,000 burn cases were reported for the immediate survivors of the Hiroshima detonation: 24,500 of these were described as serious.[1] The great ranges at which flash burns can be produced, especially in clear weather, make thermal radiation potentially more hazardous to troops in the field than either blast or nuclear radiation.

Despite the Japanese experience, flash burns are frequently overlooked in tactical nuclear warfare damage assessments, partly because of the wide variability introduced by changing weather conditions. Rain and fog greatly attenuate thermal radiation and thereby decrease the radius of effect. Other factors, such as posture of troops and possible shielding by forest cover or protective garments, further complicate assessment. This complexity has helped obscure the simple fact that unprotected troops in the open are at great risk for third-degree burns at large distances (over 6 km for a 300-kT weapon). Moreover, very-dark-skinned soldiers may suffer third-degree burns a full kilometer farther from the burst than very-light-skinned soldiers. These large ranges of effect can be calculated by applying the results presented in a recent paper[2] on the effects of local weather conditions on the thermal pulse. The calculations are found in section 2.2 of this report.

2. SKIN COLORATION AND FLASH BURNS

2.1 Vulnerability Due to Skin Color

The large variation in skin coloration among individuals gives rise to significant variations in their vulnerability to the thermal flash. Since dark skin absorbs a significantly greater fraction of incident radiation than does light skin, dark-skinned individuals suffer burns at lower radiant exposures than do light-skinned individuals.

First-degree burns are characterized by reddening of the skin, as in sunburn. Second-degree burns are more serious, with blistering followed by scabs forming over the wounds. Third-degree burns destroy

[1] *S. Glasstone and P. J. Nolan, The Effects of Nuclear Weapons, Department of the Army Pamphlet 50-3 (March 1977), 556, §12.69.*

[2] *John S. Wicklund and Ralph G. Moore, Thermal Fluence from Nuclear Explosions: Effects of Local Weather Conditions and Delivery Errors (U), Harry Diamond Laboratories HDL-TR-1904 (June 1980). (CONFIDENTIAL)*

the skin tissue, as in charring or severe scalding. Second- and third-degree burns require medical attention; first-degree burns near the eyes can cause incapacitation due to swelling of the tissues.

The differences[3] in burn sensitivities due to skin color are shown in figure 1. The radiant exposure necessary to produce burns varies with yield. One of the reasons is the fact that for higher yields the thermal emission occurs over a longer time. Thus, for the same radiant exposure, the skin has a longer time to get rid of the excess energy by reradiation, conduction to deeper levels, and evaporative cooling. Dark skin absorbs a greater fraction of the incident energy than does light skin; hence, dark-skinned people are more susceptible than lighter people. For instance, figure 1 shows that a 100-kT burst produces third-degree flash burns in very-dark-skinned people at a radiant exposure of about 6.9 cal/cm^2, while very-light-skinned people require a 10.4-cal/cm^2 radiant exposure before suffering third-degree burns. When translated into radii of effect, darker-skinned people suffer burns at radii significantly greater than lighter-skinned people do.

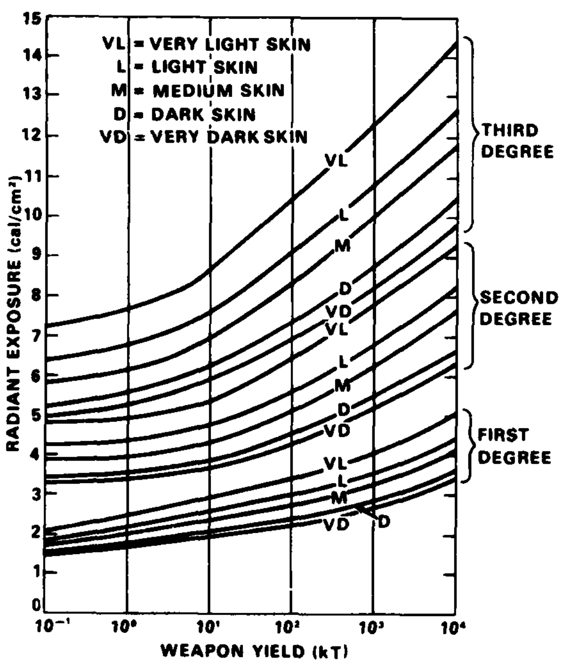

Figure 1. Radiant exposure required to produce burns on bare skin for different skin colors (from DNA EM-1, July 1972).

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[3]*Capabilities of Nuclear Weapons (U), Defense Nuclear Agency EM-1 (July 1972). (SECRET--RESTRICTED DATA)*

2.2 Effects of Local Weather Conditions

Local weather conditions affect the transmittance of thermal radiation through the atmosphere. Rain or fog decreases the transmittance, while bright days with reflective clouds and snow cover on the ground enhance it. Wicklund and Moore[2] show how data on the daily variations of transmittance can be exploited to yield the probability, P, that a given radiant exposure, Q (cal/cm^2), will be exceeded at a distance R (km) from a burst of yield W (kT). For the specific climatic conditions of northwest Europe, this probability is described by a cumulative log-normal function,

$$P\{\geq Q\} = \frac{1}{\sqrt{2\pi}} \int_u^\infty e^{-y^2/2}\, dy \qquad (1)$$

$$= \frac{1}{2}\left(1 - \operatorname{erf} \frac{u}{\sqrt{2}}\right) \quad ,$$

where

$$u = \frac{\ln Q - \mu}{\sigma} \quad ,$$

with

$$\mu = \ln \frac{3.75W}{R^{2.67}}$$

and (2)

$$\sigma = 0.55 \quad .$$

Figure 2 shows this function in the form of a nomogram: given Q, R, and W, it permits one to determine the probability that Q cal/cm^2 will be exceeded at R km for a W-kT burst. The weather of northwestern Europe is already factored into P{≥Q}, so the results obtained in this report are valid only for that region.

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[2] *John S. Wicklund and Ralph G. Moore, Thermal Fluence from Nuclear Explosions: Effects of Local Weather Conditions and Delivery Errors (U), Harry Diamond Laboratories HDL-TR-1904 (June 1980). (CONFIDENTIAL)*

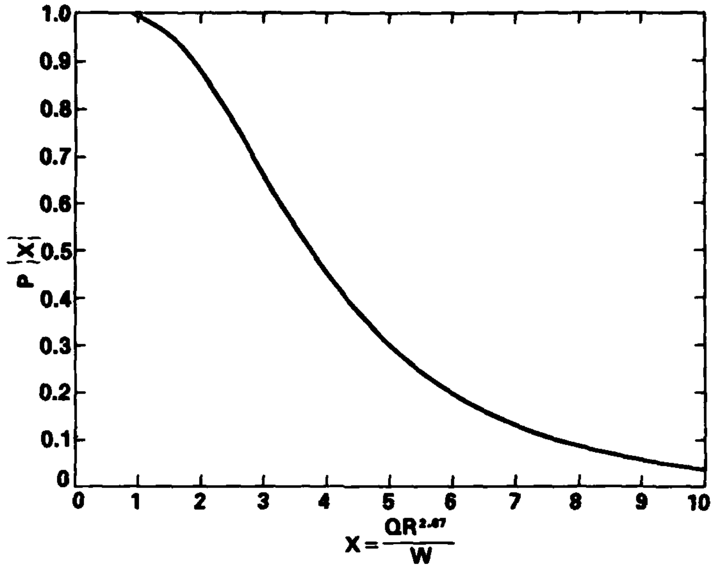

Figure 2. Nomogram for thermal flash in northwest Europe. Q is minimum expected radiant exposure (cal/cm^2), R is range (km), and W is yield (kT).

Since equation (1) gives the probability that a given Q will be exceeded, it can be combined with the information of figure 1 to give the probability of flash burns to exposed skin of any type. To simplify the calculations, the data of figure 1 can be reduced to a simple analytic form. The range of yields between 10 and 300 kT is of most interest in tactical warfare, so values of Q were taken from the curves at 10, 30, 100, and 300 kT and fitted by the method of least squares to the form $Q = aW^b$. The data are fitted very well by the form, and the resulting values of a and b are given in table 1.

Putting this formula for Q into $u = (\ln Q - \mu)/\sigma$, using equations (2), and rearranging, we have

$$u = \frac{\ln R - \left(\frac{1}{2.67}\right) \ln \frac{3.75W^{1-b}}{a}}{0.206} \quad . \qquad (3)$$

For a given yield and a particular skin type, u is a function of R. It can be used with equation (1) to calculate the probability, as a function of distance from the burst, that a person with that skin type who takes no evasive action will suffer at least second- or third-degree flash burns.

TABLE 1. CONSTANTS FOR $Q = aW^b$ FOR FLASH BURNS TO EXPOSED SKIN, $10 \text{ kT} \leq W \leq 300 \text{ kT}$

Burn type	Skin type				
	Very dark	Dark	Medium	Light	Very light
Second degree					
a	3.05	3.16	3.58	3.99	4.44
b	0.0751	0.0802	0.0776	0.0752	0.0811
Third degree					
a	5.01	5.26	5.73	6.39	7.30
b	0.0704	0.0731	0.0811	0.0770	0.0778

The results of such calculations for a range of weapon yields are presented in figures 3 to 8. Since it is customary to speak of survival probabilities when thinking defensively, the curves are plotted so that the probability of receiving burns *less* than a given severity is shown.

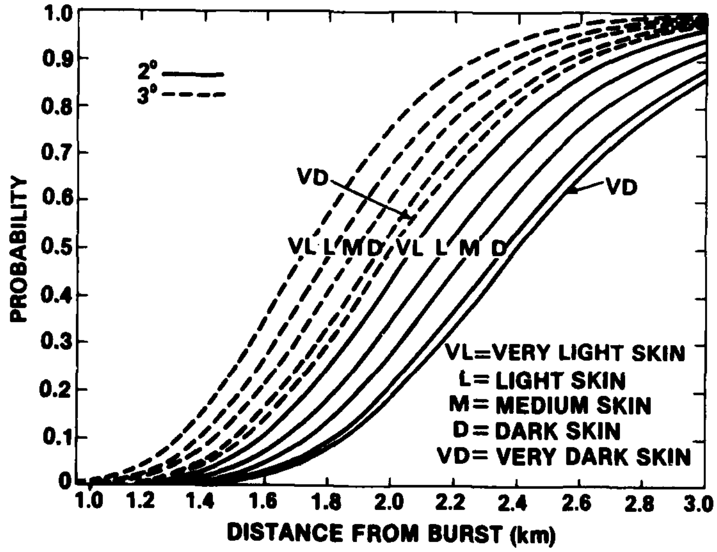

Figure 3. Probabilities of receiving burns less severe than second or third degree for different skin colors for 10-kT burst.

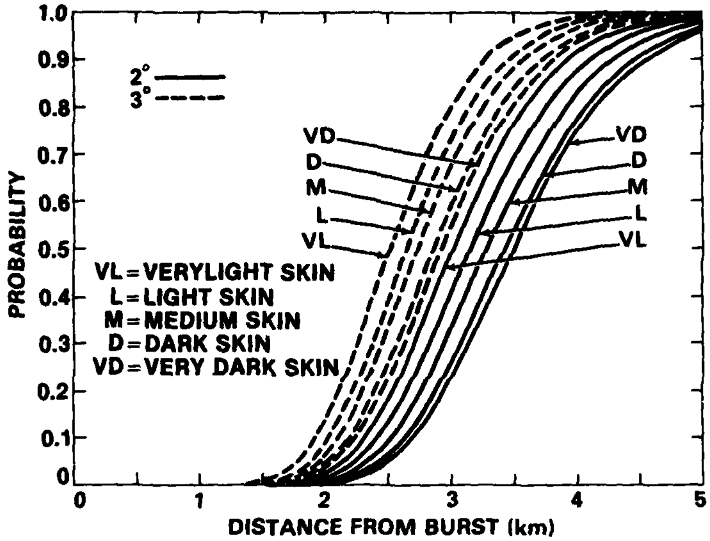

Figure 4. Probabilities of receiving burns less severe than second or third degree for different skin colors for 30-kT burst.

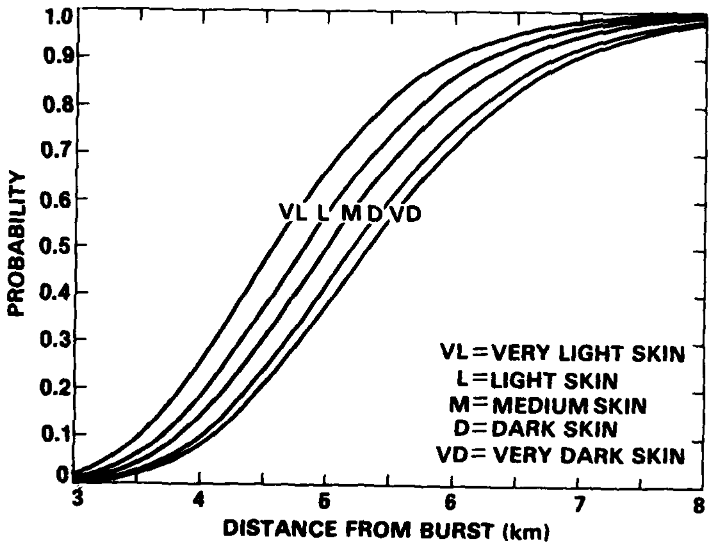

Figure 5. Probability of receiving burns less severe than second degree for different skin colors for 100-kT burst.

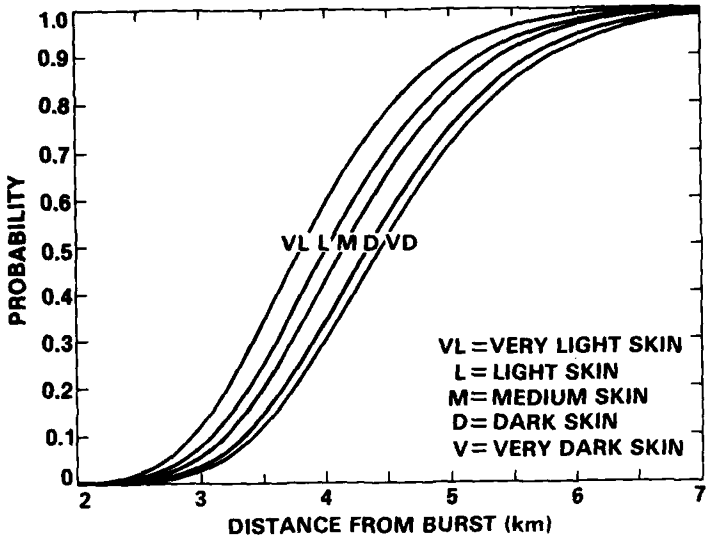

Figure 6. Probability of receiving burns less severe than third degree for different skin colors for 100-kT burst.

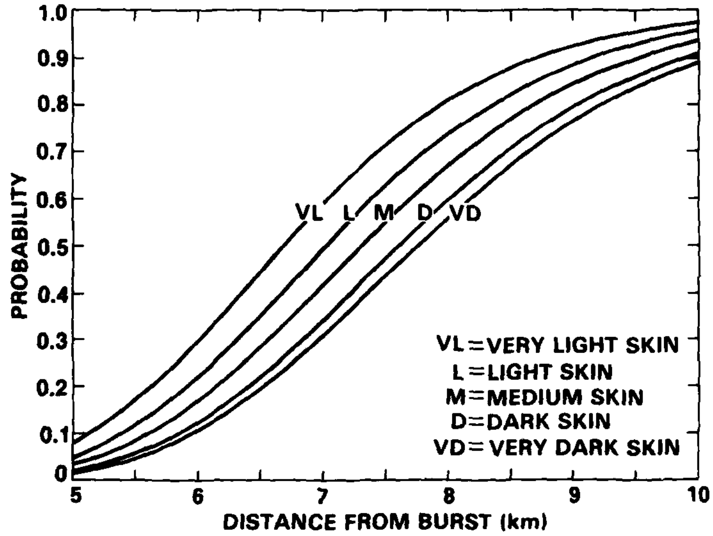

Figure 7. Probability of receiving burns less severe than second degree for different skin colors for 300-kT burst.

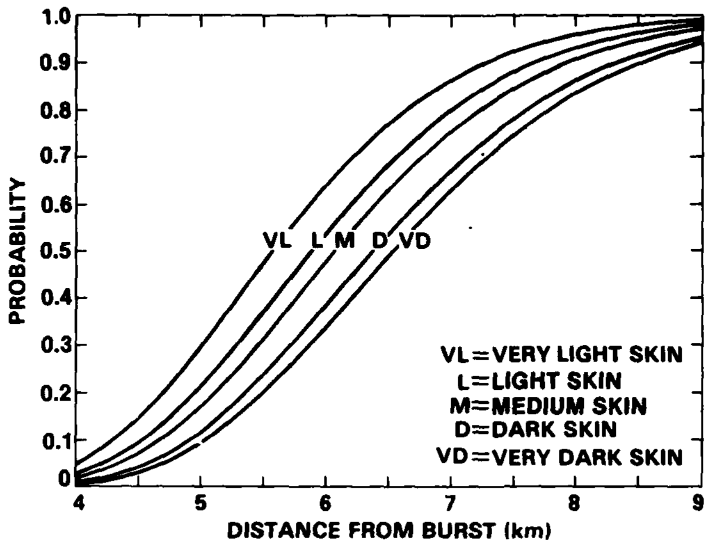

Figure 8. Probability of receiving burns less severe than third degree for different skin colors for 300-kT burst.

The effect of skin color is shown most dramatically in figure 8. Very-light-skinned soldiers have a 50-percent probability of surviving third-degree burns to exposed skin at about 5.5 km from a 300-kT burst, while very-dark-skinned soldiers must be a full kilometer farther for the same survival probability. Put differently, at 6.5 km from the burst, half of the very-dark-skinned soldiers will suffer third-degree burns, whereas only a fifth of their very-light-skinned counterparts will be similarly affected. Figure 7 indicates the large ranges at which serious thermal effects occur: a soldier of medium skin color has a 50-percent probability of receiving second-degree burns at 7 km from a 300-kT nuclear explosion.

It is evident that some sort of protection is needed for troops in the open. Protective clothing, if worn, could drastically reduce the radius of effect of the thermal pulse. Skin cream or makeup also affords some protection, especially for very-dark-skinned people. An individual soldier can take a little evasive action; a 300-kT burst takes 5 s to emit 80 percent of the energy in the thermal pulse,[1] so it is possible to take some protective action. Nevertheless, the outlook for unprotected troops in the open is not good.

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[1] *S. Glasstone and P. J. Nolan, The Effects of Nuclear Weapons, Department of the Army Pamphlet 50-3 (March 1977), 556, §12.69.*

It appears that Warsaw Pact troops have a better probability of survival than those of the United States. On the average, their forces have lighter skins than ours: this difference equates to significantly smaller damage radii for Warsaw Pact troops. In an extreme case, a simple calculation shows that as much as a 35-percent-lower casualty rate might be expected. Assume that force 1 is composed entirely of very-light-skinned soldiers and force 2 is all very dark skinned. For second-degree burns from a 300-kT burst, figure 7 shows that the 50-percent probability occurs at 6.7 km for force 1 and at 7.8 km for force 2. For a uniform distribution of n troops per unit area, the number of troops, N, for whom the probability of second-degree burns is greater than 50 percent is $N = n\pi R^2$. Thus, $N_2/N_1 = (R_2/R_1)^2 = 1.35$. This means that 35-percent more troops are at risk in force 2 than in force 1.

The real situation will never be as extreme as the above calculation. In a distinctly nonscientific survey, I asked a former artillery captain who had been stationed in Germany to categorize his unit by skin color. He estimated 5 percent very dark, 25 percent dark, 45 percent medium, 20 percent light, and 5 percent very light. Using the different constants from table 1 and weighting his unit by the above percentages resulted in a probability curve for that unit almost exactly the same as would be obtained for one composed entirely of medium-skinned troops. For contingency planning, it might be well if each commander performed a similar analysis.

3. CASUALTY CRITERIA AND CASUALTY CURVES

3.1 Casualty Criteria

The important characteristic of a tactical nuclear weapon is the number of casualties that it produces. The method of section 2.2 can be used to predict the probability of casualties as a function of range from a nuclear detonation.

Casualty criteria for thermal radiation have been developed.[4,5] These relate the type, extent, and degree of the burn to the performance of the individual. The Army Nuclear Agency Addendum[5] gives detailed calculations of how casualty criteria are developed. Taking a 10-percent variability in performance levels about an established baseline level as baseline performance, that study quantifies "functional impairment" as a 25-percent performance decrement

[4]*USACDINS Final Study, Personnel Risk and Casualty Criteria for Nuclear Weapons Effects (U), U.S. Army Combat Development Command Institute of Nuclear Studies (2 August 1971). (CONFIDENTIAL)*

[5]*Addendum to Personnel Risk and Casualty Criteria for Nuclear Weapons Effects, U.S. Army Nuclear Agency ACN 22744 (March 1976).*

in an individual. "Latent lethality" is the casualty criterion for which personnel become functionally impaired within 2 hours of exposure. Latent lethality occurs if second-degree burns are suffered over 22 percent of the body. If the radiant exposure is high enough, burns can be suffered even through clothing by conduction and convection processes: skin color is not important, but clothing type and weapon yield are. For troops in summer uniform, the Addendum[5] gives the data in table 2.

Table 2 lists the thermal levels at which personnel become functionally impaired (25-percent performance decrement) within 2 hours of exposure. Higher levels reduce the time to impairment.

TABLE 2. THERMAL CASUALTY CRITERIA (LATENT LETHALITY)

Yield (kT)	Radiant exposure (cal/cm^2)
0.01	4.4
0.1	5.2
1	8.8
10	12
100	18
1000	26

3.2 Casualty Curves

If the criteria in table 2 can be cast in the form $Q = aW^b$, equation (3) can be used to produce curves that display the probability of functional impairment as a function of range. For yields between 10 and 1000 kT, we find a good fit with a = 8.20 and b = 0.168. Equation (3) reduces to

$$u = \frac{\ln R - \ln 0.75W^{0.35}}{0.20} \quad . \tag{4}$$

Figure 9 shows the results of using equation (4). Skin coloration is not explicitly included in this graph. For 300 kT, at a range of 5.5 km there is a 50-percent probability of surviving functional impairment. This range is less than the 7 km for the same probability that a medium-skinned soldier will survive second-degree burns to unprotected skin. As a comparison, the incapacitation range for nuclear radiation dose is less than 2 km for a 300-kT burst. It is clear that some sort of thermal protection is an absolute necessity if troops are to survive the thermal pulse to this range.

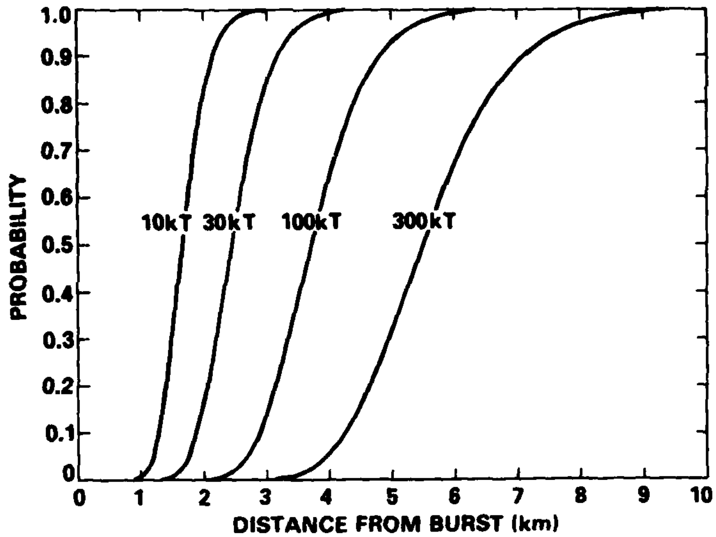
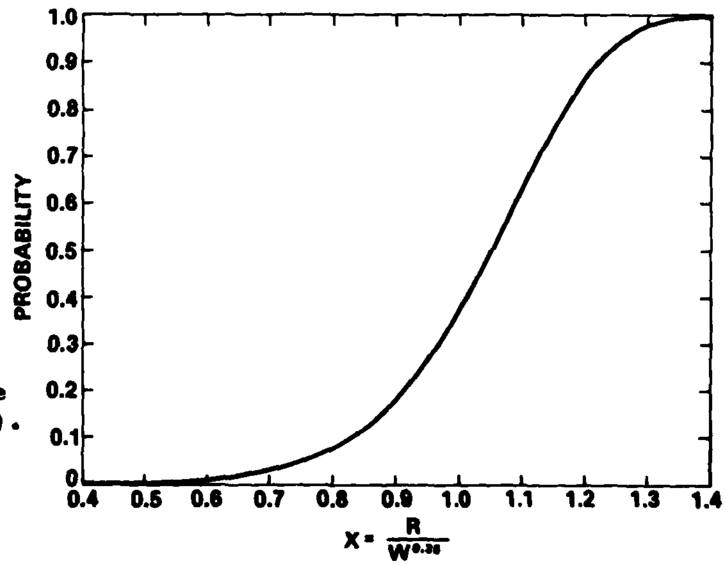


Figure 9. Probability that soldiers wearing summer uniforms will survive latent lethality by flash burns.

By using the parameter $X = R/W^{0.35}$, a nomogram similar to figure 2 can be drawn that gives the probability that troops will survive latent lethality (fig. 10). It is a cumulative log-normal function with a mean of ln 0.75 ≈ -2.9 and a standard deviation of 0.2.

Figure 10. Nomogram for obtaining probability that soldiers wearing summer uniforms will survive lethality by flash burns. R is range (km) and W is yield (kT).



3.3 Interpretation of Results

One should resist the temptation to equate the probability of surviving functional impairment with the fraction of troops surviving. Equating them may be valid when the distribution is due to individual differences between soldiers, for then one is dealing with an expected number remaining after each event. The distribution derived here for burns under summer uniforms, on the other hand, is due to variations in weather conditions and can predict the average only over a long number of battles. The results presented here are valid for long-range planning and risk evaluation, but not for specific scenarios where weather would be a determining factor.

One possible deficiency in the analysis in section 3 lies in the fact that summer uniforms were used, while equations (2) were derived from data accumulated year-round. Ideally, one should follow the method of Wicklund and Moore[2] to determine the formula for the summer only and repeat the analysis in section 3. No analysis of burns needs to be done for winter uniforms, since several layers of bulky outer garments protect the skin. In winter, ignition of clothing or of the environment (ground litter, forest fires) becomes the dominant thermal threat to troops. An analysis of ignition, similar to the one in section 3, will appear in a subsequent report.

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[2]*John S. Wicklund and Ralph G. Moore, Thermal Fluence from Nuclear Explosions: Effects of Local Weather Conditions and Delivery Errors (U), Harry Diamond Laboratories HDL-TR-1904 (June 1980). (CONFIDENTIAL)*

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